Instrumented Impactor for Testing Wood-Base Floor Panels


ABSTRACT The current ASTM method for evaluating impact resistance (ASTM E 661), which uses a leather bag filled with 14 kg (30 lb) of lead shot, is adequate for comparative rating of panels. Our objective was to obtain a more precise measure of failure initiation. An instrumented steel impactor was developed to evaluate the impact resistance of single-layer wood-base floor panels. Panel materials evaluated were plywood, waferboard (two manufacturers), and oriented strandboard. All were nominally 19 mm (3/4 in.) thick with tongue-and-groove edges and were approved for single-layer flooring. Impact resistance tests were conducted on the panels using a 14-kg (30-lb) lead-shot bag, a 14-kg (30-lb) steel impactor, and a 27-kg (60-lb) steel impactor. Floor panel damage was measured by the amount of energy absorbed by the panel, time to maximum deflection, and residual panel deflection (permanent set). The 14-kg (30-lb) impactor proved to be more precise for identifying damage initiation because the 27-kg (60-lb) impactor caused complete failure of some waferboard and oriented strandboard after only two or three drops. For all panel types, the 14-kg steel impactor caused 30 to 40% greater deflection than the 14-kg lead-shot bag for any given drop height.

KEY WORDS instrumented impact testing, floors, plywood, waferboard, oriented strandboard (OSB), test method, impact resistance

Resistance to damage from impact loading is an important performance requirement of single-layer wood-base floor panels, both during construction and throughout service. Response to impact loading depends on the characteristics of the floor (panel and framing member properties, fastening method, and support conditions) and the impactor (mass, rigidity, and velocity).

The current method accepted in the United States for measuring the impact resistance of wood floor panels is described in ASTM Test for Performance of Wood and Wood-Based Floor and Roof Sheathing under Concentrated Static and Impact Loads (E 661). A leather bag filled with lead shot to a total mass of 14 kg (30 lb) is dropped on floor panels whose framing members (joists) are fully supported over their entire length. The 14-kg (30-lb) lead-shot bag has replaced the 27-kg (60-lb) sandbag formerly specified in ASTM E 72 because the degree of sand paction was shown to affect energy absorption characteristics of the bag [1]. Researchers also concluded that a 14-kg lead-shot bag dropped from 762 mm (30 in.) represents the maximum impact load condition anticipated in service [2]. The bag-drop test provides only a qualitative indication of impact resistance and very little quantitative information. In this test, failure is defined as the height of drop after which the panel will no longer support an 890-N (200-lb) concentrated load applied through a 76-mm (3-in.)-diameter disk. This is adequate for comparing panel materials with each other or against established performance standards such as the American Plywood Association Performance Standards for Structural Use Panels [3]. However, bag-drop test results can be affected by variable energy-absorbing characteristics of the bag. Furthermore, this test does not provide information on dynamic energy. To define more precisely failure initiation, basic research in floor performance requires a test method that will provide the relationship between energy absorbed by the test panel and that remaining as kinetic energy.

The objectives of our study were as follows:

1. To develop a steel impactor instrumented with an accelerometer. Such a device is reproducible because it eliminates the energy absorption variability of a shot- or sand-filled bag. The accelerometer determines values necessary for momentum and kinetic energy analysis, and failure may be observed and defined from accelerometer data.
2. To compare impact data obtained from tests on selected single-layer wood-base floor panels using a 14-kg (30-lb) steel impactor, a 27-kg (60-lb) steel impactor, and a 14-kg (30-lb) lead-shot bag.
3. To develop baseline energy levels that can be used for comparing new floor panel materials.

Materials

English and S.I. units of measurement for most of the materials and test parameters used in our study are listed in Table 1.

Four wood-base panel materials were included in this study: two types of waferboard (designated W and L), oriented strandboard (OSB), and a western species plywood. Waferboard is a type of wood-base material made of compressed wood flakes (wafers). Products used in this study were made of aspen wafers, randomly distributed in the board. Oriented strandboard is similar to waferboard except that the flakes (strands) are arranged in layers oriented at right angles to one another. The OSB in this study was made of five layers of aspen strands. All materials were nominally 19 mm thick with tongue-and-groove edges and...
were approved for use as single-layer flooring. Five sheets of each material, 1219 by 2438 mm (4 by 8 ft), were purchased locally or furnished by the manufacturer. All were cut into 610 by 1219 mm (2 by 4 ft) panels with the tongue or groove along the long edge; the panels were used to construct 1219-mm$^2$ floor panels. Joists and headers were 38 by 140 mm (nominal 2 by 6 in.) construction lumber.

### Research Methods

#### Floor Panel Construction

Ten floor panels such as that shown in Fig. 1 were made with each of the four sheathing materials. Each floor panel consisted of one panel with a tongue edge and one panel with a groove edge, which were randomly selected from the 20 panels available for each material. The panels were fastened to the joists, which were spaced 610 mm (24 in.) on center, using 6d ring-shank nails spaced 152 mm (6 in.) on center along the outer joists and 254 mm (10 in.) on center along the intermediate joists. The headers prevented joist rotation during testing.

#### Design and Operating Principles of Impact Test

The current drop test (ASTM E 661) uses a 14-kg lead-shot bag; the impacted site is then subjected to a static load concentrated through a 76-mm-diameter disk. The impact device in our study combines these two steps. The impactor was designed to weigh about 14 kg and have a circular area of a 76-mm-diameter disk. Additionally, it had to accommodate an accelerometer and be able to hit the identical spot on successive drops. The impactor (Fig. 2) consists of a 76-mm-diameter by 57-mm-long steel tup (loading head) welded to a steel plate 122 by 32 by 305 mm (6 by 1¼ by 12 in.). An accelerometer is attached at the top center of the plate. The impactor is guided by two steel shafts; friction is minimized by bearings. Actual mass of the impactor (including accelerometer) is 13.7 kg (30.1 lb). We increased the mass to 27 kg by adding a second steel plate above the first. With this equipment, drop height was limited to a maximum of 1219 mm (4 ft).

A two-channel data collection system is used to obtain acceleration-time data from the accelerometer, and deflection-time data are simultaneously obtained from the linear-variable differential transducer (LVDT) located beneath the test specimen (Fig. 3). A force-time plot is obtained from the acceleration data by application of Newton's second law. The displacement-time plot indicates maximum displacement as well as any residual displacement.

The energy relationships for the drop test have been developed [4] and are summarized here. The energy available from the impactor just before impact can be expressed in terms of kinetic or potential energy as

$$E_0 = \frac{1}{2}mv_0^2 \quad (1a)$$

or

$$E_0 = Wh \quad (1b)$$

where $E_0$ is maximum energy available just before impact, $m$ is mass of impactor, $v_0$ is velocity at impact, $W$ is weight of impactor, and $h$ is drop height of impactor.

During impact, a portion of the available energy is absorbed by the specimen ($\Delta E_s$) and a portion remains as the kinetic energy of the impact device ($E_i$). The absorbed energy $\Delta E_s$ includes energy to (1) accelerate the specimen from rest to the velocity...

### Table 1

<table>
<thead>
<tr>
<th>Material or Test Parameter</th>
<th>S.I.</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel impactor Mass</td>
<td>14 kg</td>
<td>30 lb</td>
</tr>
<tr>
<td></td>
<td>27 kg</td>
<td>60 lb</td>
</tr>
<tr>
<td>Dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tup Diameter</td>
<td>76 mm</td>
<td>3 in.</td>
</tr>
<tr>
<td>Length</td>
<td>57 mm</td>
<td>2 1/4 in.</td>
</tr>
<tr>
<td>Disk</td>
<td>76 mm</td>
<td>3 in.</td>
</tr>
<tr>
<td>Lead-shot bag Mass</td>
<td>14 kg</td>
<td>30 lb</td>
</tr>
<tr>
<td>Drop heights</td>
<td></td>
<td></td>
</tr>
<tr>
<td>152 mm</td>
<td>6 in.</td>
<td></td>
</tr>
<tr>
<td>457 mm</td>
<td>18 in.</td>
<td></td>
</tr>
<tr>
<td>610 mm</td>
<td>24 in.</td>
<td></td>
</tr>
<tr>
<td>762 mm</td>
<td>30 in.</td>
<td></td>
</tr>
<tr>
<td>914 mm</td>
<td>36 in.</td>
<td></td>
</tr>
<tr>
<td>1067 mm</td>
<td>42 in.</td>
<td></td>
</tr>
<tr>
<td>1219 mm</td>
<td>48 in.</td>
<td></td>
</tr>
<tr>
<td>Panel deflection</td>
<td>26 mm</td>
<td>1.0 in.</td>
</tr>
<tr>
<td></td>
<td>28 mm</td>
<td>1.1 in.</td>
</tr>
<tr>
<td></td>
<td>36 mm</td>
<td>1.4 in.</td>
</tr>
<tr>
<td>Impact locus</td>
<td>152 mm</td>
<td>6 in.</td>
</tr>
<tr>
<td>Wood panel materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>19 mm</td>
<td>¾ in.</td>
</tr>
<tr>
<td>Square panels</td>
<td>1219 mm</td>
<td>4 ft</td>
</tr>
</tbody>
</table>
of the impactor, (2) bend the specimen, (3) indent the specimen under the tup, and (4) be absorbed by the impactor both through internal vibrations and elastic shortening \[4\]. For a steel tup impacting a wood-based specimen, we assume most of the absorbed energy will bend the specimen.

The kinetic energy of the impactor at time \(t\) after impact is

\[
E_t = \frac{1}{2} m v_t^2
\]  

(2)

where \(v_t\) is velocity at time \(t\) after impact.

Since

\[
E_t + \Delta E_a = E_o
\]  

(3)

then

\[
\Delta E_a = \frac{1}{2} m(v_o^2 - v_t^2)
\]  

(4)

From impulse-momentum relationships, we know the impulse of the force acting on the impactor is equal to the change in momentum of the impactor:

\[
\int P dt = m(v_o - v_t)
\]  

(5)

where \(P\) is impulse force.

Substituting Eq 5 into Eq 4 results in

\[
\Delta E_a = E_o \left(1 - \frac{v_t}{4E_o}\right)
\]  

(6)
where $E_a$ is defined as

$$E_a = v_0 \int_0^h P \, dt$$  \hspace{1cm} (7)$$

Equation 6 defines the energy absorbed by the specimen. The integrated impulse force was found by integrating the area beneath the experimentally determined force-time plot. The maximum available energy $E_0$ is found from Eq 1b.

A plot of energy absorbed ($\Delta E_a$) as a function of drop height in comparison with total available energy ($E_0$) indicates the amount of energy causing failure (Fig. 4). Failure baseline is indicated by abrupt deviation of $\Delta E_a$ from a straight-line relationship with height of drop.

### Testing Procedures

Impact tests were conducted in two phases: (1) comparison of 14- and 27-kg instrumented steel impactors, and (2) comparison of 14-kg lead-shot bag with impactors.

Five floor panels of each material were tested in each phase, and two series of impact drops were performed on each floor section. Impact locations were halfway between joists and centered 152 mm (6 in.) in from the tongue-and-groove joint (Fig. 1). The impact locations (A and B) for a particular impactor were randomly assigned for each floor panel. The impact resistance test phases are outlined in Table 2. During testing, the three joists were fully supported along their entire length by large laminated beam sections. Floor joists were attached to the beams by angle brackets to prevent bouncing.

Each series of drops began at a height of 152 mm, and height was increased by 152-mm increments until the panel failed or until the drop height reached 1219 mm. Drop heights greater than 1219 mm resulted in damage to the leather bag holding the lead shot. A rope with a friction catch device caught the bag or impactor after initial impact.

### Results and Discussion

#### Velocity of Steel Impactor

If the steel impactor is regarded as a free-falling object, the velocity $v_0$ is given as

$$v_0 = \sqrt{2gh}$$  \hspace{1cm} (8)$$

where $g$ is acceleration of gravity and $h$ is drop height. Experimental values for $v_0$ were determined by a commercial tester that measures the time taken to pass through two closely spaced light beams just before impact.

In Fig. 5 average measured velocities for different drop heights for the 14- and 27-kg impactors are compared with values calculated from Eq 8. As expected, results from the 14- and 27-kg impactors were very similar. Because of slight friction in the linear hearings, actual velocities averaged about 85% of the theoretical velocities for the 152-mm drop and increased to about 99% of theoretical for the 1067- and 1219-mm drops. Velocities were not measured for the lead-shot bag.

#### Peak Impact Deflection

Figure 6 shows the deflection-time curves for 762- to 1219-mm drops of the 14-kg impactor on one waferboard floor panel. Unfortunately, the top of the stand holding the LVDT under the floor panel was less than 38 mm below the bottom surface of the panel and only a few inches away from the center of the drop site (Fig. 3). The stand therefore acted as a positive stop, which prevented any deflection greater than approximately 36 mm. This resulted in a truncated deflection-time curve like the one shown in Fig. 6 for the 1219-mm drop height. Obviously, data from drop heights that resulted in restriction of panel de-
Deflection by the LVDT stand are not valid, and they are not included in the discussion.

For deflections less than 36 mm, certain comparisons can be made between the two steel impactors and the lead-shot bag. For all panel types, the 14-kg steel impactor caused 30 to 40% greater deflection than the 14-kg lead-shot bag for any given drop height. At equivalent impact energy ($E_0$) levels, the 27-kg impactor caused about 10% greater deflection than the 14-kg impactor. For example, average deflection for one waferboard product was 28 mm when the 27-kg impactor was dropped from 457 mm and 26 mm when the 14-kg impactor was dropped from 914 mm. The $E_0$ for both of these drops was 122 J. This agrees with results of a study by the American Plywood Association [2].

FIG. 6 — Deflection as a function of time for 14-kg impactor dropped on waferboard floor panel from various heights.

Stiffer panels would be expected to exhibit a shorter time to maximum deflection because time to maximum deflection is inversely related to material stiffness. For the same reason, time to maximum deflection will increase when the drop height is sufficient to damage the panel. Figure 7 shows time to peak deflection for the different floor panel materials tested with the two impactors and the lead-shot bag. For the waferboard and OSB panels, time to peak deflection increased as the drop height of the steel impactors increased. With the lead-shot bag drop, time to peak deflection did not increase except for the 1219-mm drop.

Time to peak deflection for plywood was less than that for the other materials and increased with drop height for only the 27-kg impactor drops. The increase in time to maximum deflection is related to progressive panel damage as the drop height increases.

Energy Absorbed

Panel damage is also reflected in the area under the force-time curve, $f P dt$, used in calculating the energy absorbed by the panel ($\Delta E_p$), as discussed earlier. Total available energy just before impact, $E_0$, and energy absorbed by the panel, $\Delta E_p$, are plotted against drop height of the 14-kg impactor in Fig. 8 and 27-kg impactor in Fig. 9. Figure 8 indicates that the 14-kg impactor
FIG. 8 — Total available energy before impact ($E_0$) and energy absorbed by the floor panel ($\Delta E_0$) for test with 14-kg impactor dropped on various wood-base floor panel materials.

FIG. 9 — Total available energy ($E_0$) and energy absorbed by the floor panel ($\Delta E_0$) for test with 27-kg impactor dropped on various wood-based floor panel materials.
did little damage when dropped on the plywood panels from a height of up to 1219 mm (48 in.). (Our equipment limited drop height to 1219 mm.) For the eight series of 14-kg drops on the plywood, $\Delta E_a$ averaged 81% of $E_a$, and $\Delta E_a$ continued to increase approximately linearly as drop height increased.

The plot of $\Delta E_a$ for the 27-kg impactor dropped on the plywood (Fig. 9) does not clearly define failure initiation. Individual $\Delta E_a$ plots did not abruptly deviate from straight lines as did some plots for waferboard and OSB (Fig. 8) where panel failure was much more sudden. Complete failure, splintering on the bottom side of the plywood (Fig. 10), occurred at the drop height of 1067 mm for the 27-kg impactor for six of the seven panels and at 914 mm for the remaining panel. The $\Delta E_a$ values for these drops were not considered reliable. Panel deflection was truncated at 36 mm. as discussed previously.

The $\Delta E_a$ plots from dropping the 14-kg impactor onto the waferboard and OSB panels (Fig. 8) indicate damage in most panels at the 762-mm drop height, where the $\Delta E_a$ plots deviate from a straight-line relationship with drop height. Again, $\Delta E_a$ values for some of the 1067- and 1219-mm drops were not considered reliable and were omitted from the graphs.

Only one of the 16 waferboard panels failed completely when the 14-kg impactor was dropped from 1219 mm (Fig. 11). In contrast, only one of the eight OSB panels survived the 1219-mm drop.

Identifying a damage initiation point from the $\Delta E_a$ plots of 27-kg impactor drops on the waferboard and OSB panels (Fig. 9) was impossible in most cases. Complete failure occurred at a drop height of 610 or 762 mm for the waferboard panels and at 457 or 610 mm for the OSB panels. Recorded deflection data at these drop heights were again unreliable.

Only 3 of the 20 panels tested with the 14-kg lead-shot bag failed completely. One waferboard panel and two OSB panels failed when the lead-shot bag was dropped from 1219 mm.

**Residual Panel Deflection**

Residual panel deflection (permanent set) after dropping the lead-shot bag and steel impactors would appear to be a measurement of damage to the floor panel (Fig. 6). In some cases this was true; in other cases, results were inconsistent. Dropping the lead-shot bag resulted in a residual deflection $>2.5$ mm (0.10 in.) in only three floor panels (one waferboard and two OSB). In each case the drop height was 1219 mm, and in each case the panel failed.

Residual deflections $>2.5$ mm (0.10 in.) were common when the 14- or 27-kg impactor caused noticeable damage to the waferboard or OSB panels, and agreement with $\Delta E_a$ as a damage indicator was usually good (compare Figs. 8 and 12). However, with plywood, complete failure did not always result in large residual deflections. For example, after the 27-kg impactor was dropped from a height of 1067 mm, plywood residual deflection...
exceeded 2.5 mm in only one instance (Fig. 12), although all seven panels failed completely. The splintery failure in the plywood indicates that plywood is a more resilient material than waferboard and OSB, which exhibited more “brash” failures. This resiliency is demonstrated by less residual deflection.

Conclusions

1. Plots of energy absorbed by 1219-mm² floor sections impacted with a 14-kg instrumented impactor indicate the possibility of identifying failures in wood-base floor panels.

2. Deviations from a linear relationship between energy absorbed by the panel and drop height of the 14-kg impactor are a good indicator of damage initiation for those waferboard and OSB panels that failed at peak deflections below 36 mm.

3. Other indicators for waferboard and OSB panel damage are time to maximum deflection and residual panel deflection (permanent set), both of which increase substantially with panel damage.

4. The 27-kg impactor is too heavy for precise determination of damage initiation in the OSB and waferboard panels because some panels failed after as few as two or three drops. On the other hand, the 1219-mm drop height limit of the apparatus used is not sufficient to define failure of plywood panels when the 14-kg impactor is used.
5. The lead-shot bag-drop test is adequate for comparative rating of panels for meeting performance requirements, but the instrumented steel impactor gives a more precise measure of failure initiation that can be used in basic floor performance research.

References


